EFFECT OF HEAT TREATMENT ON CORROSION BEHAVIOR OF SS316 STAINLESS STEEL IN SIMULATED BODY ENVIRONMENT

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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Effect of Heat Treatment on Corrosion Behavior of SS316 Stainless Steel in Simulated Body Environment"* is written by *Mohd Asyraf Bin Che Azmi*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This thesis is entitled about the effect of heat treatment on corrosion behavior on SS316 stainless steel in simulated body environment. Biomedical materials are very important in the modern world to manufacture the variety of prosthetic devices which are the artificial replacements for human body. These artificial replacements are use in a biological system such as the human body in an effort to provide the function of the original parts. When a metal device is implanted into human body, it is continually exposed to extracellular tissue fluid. This interaction can lead to either failure of the implant or have an adverse effect on the patient resulting in the rejection of the implant by the surrounding tissue or both. The objective of this project is to investigate the effect of stress relief on corrosion behavior of SS316 stainless steel in simulated body fluid. Stress relief had been performed to the sample with two different time and temperature. Stress relief is used to relieve stresses that remain locked in a structure as a consequence of a manufacturing sequence such as machining. The sample was prepared for electrochemical test. Electrochemical tests using a potentiostat WPG1000 have also been conducted and reported in this thesis. The corrosion rates of the alloys were then compared.

ABSTRAK

Tesis ini mengkaji tentang pengaruh proses pemanasan terhadap kelakuan pengaratan terhadap keluli tahan karat SS316 dalam simulasi larutan badan. Bahan bioperubatan amat penting pada zaman yang moden ini untuk menghasilkan pelbagai jenis peranti buatan sebagai tulang gantian. Peranti buatan ini digunakan dalam sistem biologi seperti tubuh manusia dalam usaha untuk menyediakan fungsi dari bahagian-bahagian yang asli.Apabila peranti ini ditanam di dalam tubuh manusia pendedahan terhadap cecair rangkaian ekstraseluler berlaku secara berterusan. Interaksi ini boleh menyebabkan kegagalan implan atau mempunyai kesan buruk pada pesakit yang mengakibatkan penolakan implan dengan rangkaian sekitarnya atau kedua-duanya.. Tujuan projek ini adalah untuk mengetahui pengaruh legaan tekanan bagi keluli tahan karat SS316 dalam larutan simulasi badan. Legaan tekanan telah dilakukan pada sampel pada dua waktu dan suhu yang berbeza. Legaan tekanan digunakan untuk melegakan tekanan tetap yang tersimpan di dalam struktur sebagai kesan daripada proses pembuatan seperti pemesinan. Sampel disediakan untuk ujian elektrokimia. Ujian elektrokimia dengan mnggunakan WPG 100 potentiostat telah dijalankan dan dilaporkan di dalam tesis ini. Kadar karatan keluli ini seterusnya dibandingkan.

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LIST OF SYMBOLS

E_p	Primary passivation potential
I_c	Critical current density
I_p	Passive current density
β_c	Cathodic slopes
β_a	Anodic slopes
e_{corr}	Corrosion potential
i_{corr}	Current density
Log I	Log Current
Fe	Ferum
Cr	Chromium
KH_2PO_4	Potassium dihydrogen
KCl	Kalium chloride
HCl	Hydrochloric acid
HNO_3	Nitric acid
HPO_4^{2-}	Mono hydrogen phosphate
Ca^{2+}	Calcium ion
Mg^{2+}	Magnesium ion
Cl^-	Chlorine ion
Na^+	Sodium ion
CO_2	Carbon dioxide
Na_2HPO_4	Disodium phosphate
NaCl	Kalium chloride

LIST OF ABBREVIATIONS

PBS	Phosphate buffered saline
HBSS	Hank's balanced salt solution
ASTM	American Standard for Testing and Material
SCC	Stress corrosion cracking
CoCrMo	Cobalt-chromium-molybdenum
WE	Working electrode
RE	Reference electrode
SCE	Saturated calomel electrode
SBF	Simulated body fluid
MEM	Minimum essential medium

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Biomedical materials are very important in a modern world to manufacturing the variety of prosthetic device which is the artificial replacement. These artificial replacements as shown in Figure 1 are use in a biological system such as the human body in an effort to provide the function of the original parts. Stainless steels, cobalt-chromium based alloys and titanium alloys are three major biomedical materials that we use as implant (Douglas C. Hansen, 2008).

As the global population increases in age, there is a parallel increase in the number of implantation procedures. On the other hand, as new devices and technologies are developed, there will be a continuing research for the understanding and characterization of how metal surfaces of implants interact with their surrounding physiological environment.

The first requirement for any material to be placed in the human body is that it should be biocompatible and not cause any adverse reaction in the body Biocompatibility is the capability of a prosthesis implanted in the body to exist in harmony with tissue without causing deleterious changes and the ability of a material to perform with an appropriate host response in a specific application (Buddy D. Ratner, 2000). The material must withstand the body environment and not degrade to a point that it cannot function in the body as intended.

Figure 1.0: Implant components

Source: Douglas C. Hansen (2008)

Artificial implants are generally made of polymeric, metallic, ceramic material or combinations of this material and depending on the intended use. Metals or alloys used in the human body must have a high corrosion resistance and must not be treated or used in a configuration that would degrade the corrosion behavior. Therefore, various in vitro and in vivo tests have to be carried out in order to identify the suitable material for use as artificial implants (Gurappa, 2002).

Nowadays, corrosion is one of the major issues resulting in the failure of biomedical implant. The types of corrosion that occur to the currently used alloys as an implant are pitting, crevice, galvanic, stress-corrosion cracking, corrosion fatigue, and fretting corrosion. Any time a foreign material is placed inside the human body, the manner in which that material will affect the body must be considered. There are many causes that contribute to the corrosion of metals when placed inside the human body. After surgery the pH surrounding the implant is reduced to a pH between 5.3-5.6 typically due to the trauma of surgery. Infectious microorganisms and crevices formed between components can reduce oxygen concentration, both of which contribute to the corrosion of the implant. Besides, corrosion and surface oxide film dissolution are the two mechanisms for introducing additional ions into the body. Extensive release of ions from prosthesis can result in adverse biological reactions and can lead to mechanical failure of the device.

Austenite stainless steel in particular type 316 is the common biomedical material use in medical implant such as stents and orthopedic replacements. This is because SS316 are relatively low cost, ease of fabrication and reasonable chemical stability (Yee-Chin Tang et al. 2006). Type 316 is an austenitic chromium nickel stainless steel containing molybdenum. This addition increases general corrosion resistance, improves resistance to pitting from chloride ion solutions, and provides increased strength at elevated temperature. Surface modification of SS316 stainless steel is one alternative that is already in practice such as the coating of the alloy with hydroxyapatite to minimizing the release of metal ions by making it more corrosion resistant. Besides there are many surface modification such as hard coating, stress relieving, laser nitriding, ion-implantation and bioceramics to improve the performance characteristic of the biomedical implants and improving the lives of their recipients.

1.2 PROBLEM STATEMENT

To investigate the effect of stress relief to the stainless steel SS316 either it can reduce or contribute to corrosion to the SS316 stainless steel. Stress relief is used to relieve stresses that remain locked in a structure as a consequence of a manufacturing sequence such as machining. Artificial implant such as hip prostheses must be formed to exacting size and shape specification to fit the internal dimensions of the human bones. The stress is directly proportional to the bigger and more complex part. These stresses can cause distortions in the part long term. If the parts are clamped in service, then cracking could occur. As a conclusion, for these reasons, stress relieving process is often necessary.

1.3 PROJECT OBJECTIVES

The main purpose of this project is to study the effect of heat treatment on corrosion behavior of SS316 in phosphate buffered saline (PBS) and Hank's balanced salt solution (Hank's solution) as simulated body environment. Besides, this study is mean to investigate experimentally, the behavior by performing the electrochemical test to the SS316 stainless steel.

1.4 PROJECT SCOPES

In order to obtain the objectives, it should have proper arrangement of project scopes. The lists of scopes are as followed.

(i) Sample preparation for electrochemical study of SS316 in simulated body environment

(ii) Stress relieving sample at temperature 415°C and 900°C for 1 hour and 1 ½ hours. Then, followed by slow cooling at room temperature.

(iii) Metallographic process consists of grinding, polishing and etching to get the microstructure of the sample.

(iv) Microstructure analysis of specimen by using Inverted Microscope.

(v) Electrochemical study of SS316 stainless steel by using potentiodynamic polarization.

(vi) Corrosion rate analysis by using IV man software.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Corrosion is the gradual degradation of materials by electrochemical attack. It is a concern particularly when a metallic implant is placed in the hostile electrolytic environment provided by the human body. Even though the freely corroding implant materials used in the past have been replaced with modern corrosion resistant super alloys, deleterious corrosion processes have been observed in certain clinical settings (D.Sharan, 1999). Corrosion is one of the major processes affecting the life and service of orthopedic devices made of metals and alloys used as implants in the body. Chemical stability, mechanical behavior and biocompatibility in body fluids and tissues are the basic requirements for successful application of implant materials in bone fractures and replacements. In order for a material to be biocompatible, it must not adversely affect the physiological environment and the environment should not have detrimental effects on the material.

Implantable materials or biomaterials are utilized to repair, assist or replace living tissue or organs that are functioning below an acceptable level. A wide range of metals and their alloys, polymers, ceramics and composites are used in surgically implanted medical devices and prostheses and dental materials. Most implanted devices are constructed of more than one kind of materials. Since the early 1900s, metal alloys have been developed for these applications to provide improved physical and chemical properties, such as strength, durability and corrosion resistance.

2.2 STAINLESS STEEL

There are three main types of stainless steels austenitic, ferritic, and martensitic. These three types of steels are identified by their microstructure or predominant crystal phase.

Austenitic steels have austenite as their primary phase (face centered cubic crystal). These are alloys containing chromium and nickel (sometimes manganese and nitrogen), structured around the Type 302 composition of iron, 18% chromium, and 8% nickel. Austenitic steels are not hardenable by heat treatment. The most familiar stainless steel is probably Type 304, sometimes called T304 or simply 304. Type 304 surgical stainless steel is austenitic steel containing 18-20% chromium and 8-10% nickel.

Ferritic steels have ferrite (body centered cubic crystal) as their main phase. These steels contain iron and chromium, based on the Type 430 composition of 17% chromium. Ferritic steel is less ductile than austenitic steel and is not hardenable by heat treatment.

The characteristic orthorhombic martensite microstructure was first observed by German microscopist Adolf Martens around 1890. Martensitic steels are low carbon steels built around the Type 410 composition of iron, 12% chromium, and 0.12% carbon. They may be tempered and hardened. Martensite gives steel great hardness, but it also reduces its toughness and makes it brittle, so few steels are fully hardened (H.S Khatak and Baldev Raj, 2006).

Type 316 is an austenitic chromium nickel stainless steel containing molybdenum. This addition increases general corrosion resistance, improves resistance to pitting from chloride ion solutions, and provides increased strength at elevated temperatures.

In medical implants, stainless steel in particular Type 316 is commonly used such as to make stents and orthopedic replacement. This is because stainless steel 316 are relatively low cost, ease of fabrication and reasonable chemical stability. The compositions of this metal are 17-20% Cr, 13-15 % nickel and 2-3 %molybdenum, and small amounts of other elements (Table 1). The "L" means "low carbon", the (<0.03%) carbon is a maximum value, in % by weight and is therefore not susceptible to intergranular corrosion due to precipitation of Cr-carbides at the grain boundaries. Chromium is the element mainly responsible for the high passivation ability of these alloys. The minimum amount of chromium is necessary to form a stable passive chromium oxide film because this film that is the basis for the corrosion resistance of all stainless, and most nickel base, corrosion-resistance alloys.

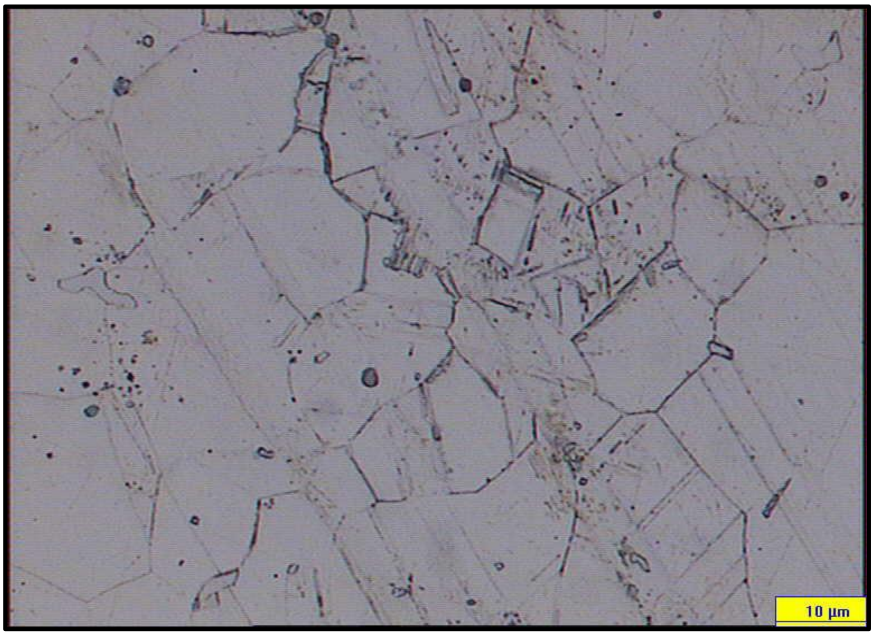

Figure 2.1: Microstructure of SS316 Stainless Steel at magnification 10x

Source: Biomedical Engineering Handbook (2000)

Table 2.1: Mechanical properties of SS316 stainless steel

Grade	Tensile Strength (MPa) min	Yield Strength 0.2% Proof (MPa) min	Elongation (% in 50mm) min	Hardness Rockwell B (**HR B**) max	Hardness Brinell (**HB**) max
SS316	515	205	40	95	217

Source: AK Steel Sheet Product (2007)

Table 2.2: Stainless Steel SS316 Composition

Element	**Composition %**
Carbon	0.08
Manganese	2.00
Phosphorus	0.045
Sulfur	0.030
Silicon	1
Chromium	17
Nickel	13
Molybdenum	2.5
Iron	Balance

Source: Heat Treating Volume 4, ASM International Handbook (1991)

2.3 METALLURGY

2.3.1 Heat Treatment

Heat treatment is the process of controlled heating and cooling of metals. The purpose of heat treatment is to cause desired changes in the metallurgical structure and thus in the properties of metal parts (George E. Totten et al. 2002). Heat treatment is sometimes done due to manufacturing processes that either heat or cool the metal such as welding or forming. In addition, heat treatment also to increasing the strength of material, but it can also be used to alter certain manufacturability objectives such as improve machining, improve formability and restore ductility after a cold working operation.

Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics. Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material.

2.3.2 Stress Relieving

Stress relieving is the process to relieve the internal stresses and there is no microstructure change happen during the process. Internal stresses are those stresses which can exist within a body in the absence of external forces. There are also known as residual stresses or locked in stresses. The internal stresses are happen during the different operation such as solidification of castings, welding, machining, shot peening, case hardening and precipitation. Besides, the internal stresses under certain conditions can have adverse effects. It can prove by steel with residual stresses under corrosive environment fail by stress-corrosion cracking but in general failure by stress-corrosion cracking occurs under the combined action of corrosion and externally applied stresses (Janez Urevc et al. 2009).